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## The Use of Tympanometry to Detect Aerotitis Media in Hypobaric Chamber Operations

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**Diagnosis and quantification of aerotitis media were performed using a modified commercially-available tympanometer under hypobaric conditions. Subjects were 22 males and 9 females, 22-43 years of age, who were tested in each ear with the tympanometer prior to and after exposure, sequentially at the barometric pressure plateaus of 706, 656, 609, 586, 564, and 522 mm Hg, and following an induced ear block during a 1-min descent from 522 to 586 mm Hg. Each subject was examined once either alone or in pairs during a 90-min exposure. Aerotitis media was detected using tympanometry at simulated altitude as evidenced by the difference between measurements made during induced ear blocks and those made prior to induction, as well as following relief of the pressure differential with the Valsalva maneuver. There were no significant differences between pre- and post-induced aerotitis media values at 586 mm Hg, or between pre- and post-hypobaria. Our study suggests that tympanometry can be a valuable tool in managing aerotitis media in the aeromedical environment.**

**A**EROTITIS MEDIA (barotrauma, ear block) is the most prevalent medical problem occurring within hypobaric chamber (6) and aviation operations (7). The condition, which may occur unilaterally or bilaterally, results from the inability to equilibrate pressure within the middle ear cavity through the Eustachian tubes following an increase in ambient air pressure (8). The resulting pressure differential between the middle ear and atmosphere stretches the tympanic membrane producing discomfort or pain. The relative negative middle ear pressure can cause a narrowing or collapse of the Eu-

stachian tube, promoting a self-perpetuating pathological process (2) which may be further aggravated by transudation of fluid into the middle ear cavity (3).

In healthy individuals, pressure in the middle ear can be equalized with ambient atmospheric pressure by swallowing, yawning, or tensing the muscles of the throat, procedures which contract the pharyngeal muscles and open the orifices of the Eustachian tubes, thereby ventilating the middle ear. Another, perhaps more effective, means of ventilating the middle ear, and one which is frequently used in hypobaric chambers and the aviation environment, is the Valsalva maneuver. This method forces air into the Eustachian tubes to equalize middle ear pressures with the ambient air pressure.

If the existing pressure differentials are sufficient to collapse the Eustachian tubes, middle ear ventilation may not be possible by any of the previously mentioned methods. In this situation, the pressure differentials may be equalized by returning to a lower ambient pressure (i.e., higher altitude). Once the pressures are equalized, techniques to ventilate the middle ear may again be attempted.

Inability to equalize pressure may occur more readily when the Eustachian tubes or their openings are swollen due to inflammation or infection. In these instances, the use of short-acting antihistamines or decongestants can be helpful for treatment. To lessen the risk of aerotitis media in the aeromedical environment, it is normal practice to deny hypobaric exposure to those individuals who have difficulty ventilating their middle ears.

Although these methods for treating or reducing the incidence of aerotitis media are useful, it is often difficult to fully evaluate their success because there has been no convenient, objective means of consistently assessing the presence or absence of transient pressure-related problems of the middle ear. Traditionally, aerotitis media has been detected by the presence of

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subjective symptoms (i.e., pain) and/or by direct otoscopic visualization. Both methods have inadequacies. Subjective symptoms are prone to individual variation in perception, tolerance, and reporting of pain. Directly assessing middle ear function requires observation with an otoscope to examine tympanic membrane movement in response to either a Valsalva maneuver or transient pressure changes introduced into the external ear canal with a pneumatic otoscope. However, because observational assessment of tympanic membrane movement is also subjective, experienced examiners may be uncertain or disagree on both the actual findings and the interpretations of those findings (5,16). Ingelstedt *et al.* (14) developed a microflow system which is capable of detecting aerotitis media indirectly by measuring middle ear pressure changes. The system is cumbersome and requires technically skilled personnel to operate. Groth *et al.* (12) compared a quantitative impedance method to the microflow method and found comparable results.

The tympanometer is an impedance device designed to detect congestive pathology in the middle ear without the use of otoscopy. A number of studies have suggested that tympanometry may provide a method that requires less experience and subjective interpretation on the part of the examiner (1,4,17,19). It has been used successfully in routine clinical screening of pediatric populations for middle ear defects, and to detect and follow the results of middle ear effusions (5,15,16,17). Tympanometry has also been used to detect middle ear pathology prior to flight and on various studies of susceptibility to aerotitis media (7,20). To date, however, no studies have been reported which specifically examine the ability of tympanometry to detect aerotitis media while it is present in the hypobaric environment. We performed tympanometric measurements on 31 test subjects after inducing aerotitis media following a rapid increase of atmospheric pressure from 522 to 586 mm Hg in a hypobaric chamber, and compared the results with measurements previously made at 586 mm Hg without the ear block. Additionally, serial measurements were made during ascent to characterize the tympanometer operations at altitude. Pre- and post-hypobaric exposure measurements were made to detect possible residual effects of aerotitis media.

## METHODS

All tympanometric measurements in this study were made with a modified Grason-Stadler GSI-27 tympanometer. Modifications were necessary because the instrument was designed for use at barometric pressures greater than 630 mm Hg. To allow use at atmospheric pressures as low as 522 mm Hg, the Grason-Stadler Co. reduced the internal volume of the instrument's air reservoir (modification no. GS1727-2010A) and probe syringe (modification no. GS1727-0410A). With these changes, the instrument was able to achieve its pressure sweep more rapidly and thus compensate for the decreased ambient pressure. Two fixed test cavities (0.5 and 2.0 ml) provided by the Grason-Stadler Co. were used to validate instrument calibration from 760–522 mm Hg.

Adult volunteers were 22 males and 9 females who served as test subjects after giving their informed con-

sent. Subjects ranged in age from 22–43 years. Each was screened with a medical history and a Flying Duty Medical Exam prior to inclusion into the study. Potential subjects with any otorhinolaryngology pathology or contraindication to altitude exposure were excluded from participation.

Test subjects were exposed to hypobaric conditions up to a simulated altitude of 522 mm Hg in the USARIEM Hypobaric Chamber in Natick, MA. Each subject underwent one exposure lasting approximately 90 min. The flight profile is outlined in Fig. 1. We observed in our 20 years of hypobaric chamber operations that 90% of spontaneous cases of aerotitis media occurred between 522 mm Hg and sea level pressure. Therefore, 522 mm Hg was chosen as the lowest pressure for data collection in this study. Subjects were exposed alone or in pairs, and none received supplemental oxygen during the exposure. Both ears were tested in every subject, one at a time.

Each subject received 11 tympanometer examinations: at sea level prior to entering the hypobaric chamber, during ascent stopping at 706, 656, 609, 564, and 522 mm Hg to determine if the ear canal volume measurements changed as a function of hypobaric pressure, and at 586 mm Hg on ascent for comparison with the data collected at the same pressure following the induced "ear block." After reaching 522 mm Hg, subjects were asked to refrain from ventilating their middle ears during a 1-min descent to 586 mm Hg. This induced mild symptoms of aerotitis media (fullness or some discomfort) in at least one ear of each subject. After tympanometric measurements were made during the induced aerotitis media, each subject performed a Valsalva maneuver to relieve the ear block and to provide measurements of ventilated middle ears for comparison to measurements made at 586 mm Hg on ascent. Then, to determine if the tympanometer could be used to differentiate between aerotitis media and an over-inflated middle ear, the subject held a forced Valsalva maneuver while measurements were made. A final tympanogram was performed following return to sea level pressure to detect any residual aerotitis media and to determine if post-exposure values recovered to pre-exposure values. Because body position has been shown to affect Eustachian tube function (13), all tests were accomplished with the subject seated upright. All measurements were

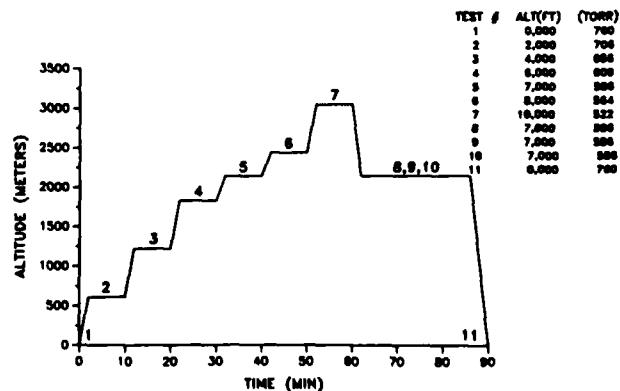


Fig. 1. Flight profile showing the barometric pressure/altitude plateaus where 11 tympanometer examinations were accomplished on each subject during a 90-min exposure.

performed by one investigator to minimize potential discrepancies in technique, although other studies (1,4,17,19) suggest there is very little difference in measurements by different operators using standard procedures.

The tympanometric measurements used to determine middle ear conditions were: ear canal volume, which represents the space between the probe tip and tympanic membrane; tympanic volume (Tymp Peak), which represents volumetric displacement of the tympanic membrane; and tympanic pressure (Tymp Pressure) measured in decaPascals (1.0 daPa = 0.039 in. H<sub>2</sub>O). Tymp pressure represents the amount of pressure used to displace the tympanic membrane. A brief explanation of the operating principles of the tympanometer is found in the addendum.

Standard statistical procedures from the Biomedical Computer Programs (BMDP) library were used for data analysis (9). A three-way (subject  $\times$  level of hypobaria  $\times$  test condition) analysis of variance (ANOVA) was used to compare tympanic membrane measurements before, during, and after voluntarily-induced aerotitis media. If significant effects or interactions between factors were indicated by ANOVA, Tukey's critical difference was calculated and used to locate significant differences. The level of significance for all statistical analyses was set at  $p < 0.05$ .

## RESULTS

Three patterns of tympanograms that fit Jerger's Type A, B, and C classifications (15) of middle ear status were identified during testing. The Type A pattern reflects a normal tympanogram with maximum compliance (neutral position) at or near ambient air pressure (Fig. 2). Type B represents a flat, non-responsive contour usually associated with middle ear fluid, thickened drum, or impacted cerumen. The tympanometer expresses this data in terms of a "full ear block" with no tymp volume peak (NP), no tymp pressure (NP), and no reflex response (NR) or tone (NT) as illustrated in Fig. 2. Type C classification is indicative of maximum compliance at a considerably large negative pressure associated with retracted tympanic membrane. This "partial ear block" (Fig. 2), exhibited large negative numbers (e.g., -410 daPa) when the pressure differential between the middle ear and ambient environment dis-

tended the tympanic membrane, but did not entirely eliminate function.

Of the 62 measurements made during induced aerotitis media, 44 (70%) were comparable to Type B tympanograms and designated "full ear blocks" while 14 (23%) typify the Type C category or "partial ear blocks." In one ear of four different subjects, aerotitis media was not induced, and their pattern remained consistent with Type A. Resolution was accomplished with the Valsalva maneuver in all subjects exhibiting a "full or partial ear block."

Subsequent tympanometer examinations during forced (held) Valsalva maneuvers found 57 (92%) elicited results consistent with a "full ear block" as was seen during aerotitis media. A "partial ear block" was observed in one ear of one subject. Also, in one ear of four different subjects (unrelated to the four subjects with aerotitis media) the Valsalva maneuver could not be sustained. The only definitive difference between aerotitis media and forced Valsalva maneuver was observed in the mean ear canal volume data, where the forced Valsalva ( $1.98 \pm 12$  ml) was significantly lower ( $p < 0.5$ ) than the aerotitis media ( $2.13 \pm 10$  ml).

Table I and Fig. 3 show that, as the barometric pressure was reduced, the tympanometer measurement values became larger in subjects with adequately ventilated ears. Also included at each barometric pressure where tympanometer examinations were performed are the values calculated using Boyle's Gas Law, which used the mean group ear canal volume of 1.41 ml measured at sea level.

There were no significant differences observed between pre- and post-induced aerotitis media values at 586 mm Hg, or between pre- and post-hypobaria values (Table II).

## DISCUSSION

Results of this study suggest that a modified, commercially available tympanometer can be used to detect and follow aerotitis media during hypobaric operations. Detection is based on alteration in the tympanogram pattern consistent with partial or complete disruption of middle ear function. Retraction of the tympanic membrane results in a progressive decrease in compliance due to a negative pressure differential between ambient air and the middle ear. Eventually, the pressure differential increase becomes sufficient to immobilize the

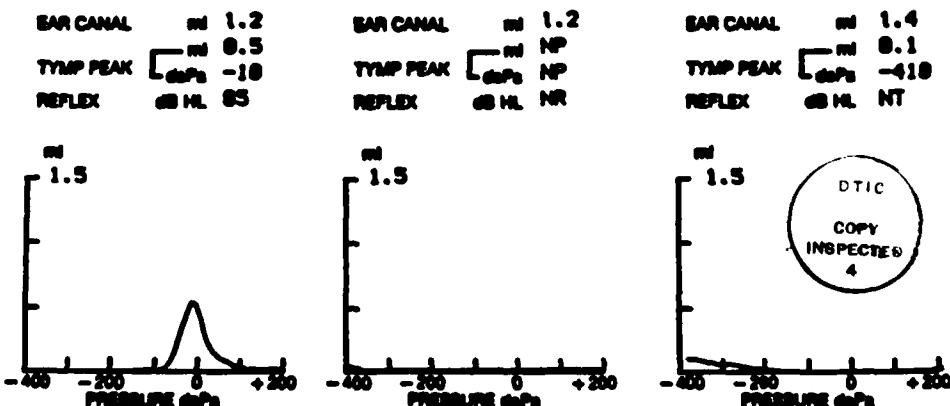


Fig. 2. Tympanogram data and plots showing examples of: normal middle ear status on the left, a flat non-responsive contour described as a "full ear block" in the center, and a large negative pressure resulting in retracted tympanic membrane and explained as a "partial ear block" on the right.

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TABLE I. EFFECT OF DECREASING BAROMETRIC PRESSURE ON EAR CANAL VOLUMES.

	mm Hg					
	760	706	656	609	564	522
TYMP	1.41 ± 0.07	1.65 ± 0.08	1.92 ± 0.08	2.20 ± 0.09	2.50 ± 0.10	2.86 ± 0.09
BOYLES	1.41	1.52	1.64	1.77	1.91	2.10

Values for "TYMP" are Mean ± S.E.M., ml, N = 62.

Values for "BOYLES LAW" are calculated on 1.41 ml at 760 mm Hg.

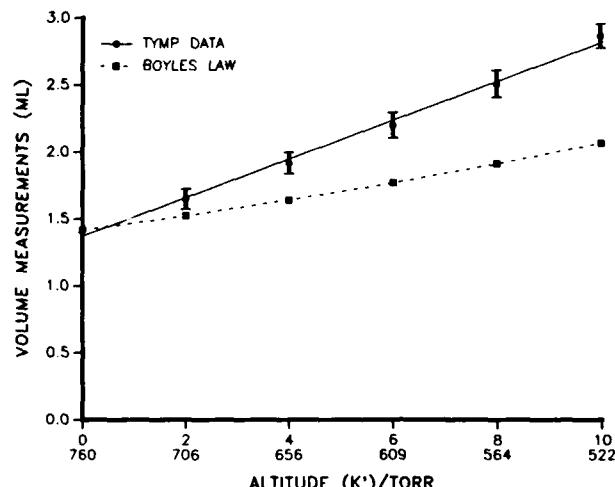


Fig. 3. Each tympanometer point represents the mean of 62 values (±S.E.M.). The regression equations for the tympanometer data and Boyle's law are  $y = 0.14x + 1.37$ ,  $r = 0.997$  and  $y = 0.64x + 1.40$ ,  $r = 0.997$ , respectively.

tympanic membrane producing a flat curve. The negative shift of a tympanometer curve that coincides with a negative middle ear pressure has been documented in previous studies where the shape of the curve provides clinical value used in detecting disease (4,10,15,18,19). Our results suggest a similar mechanism through which a flat curve is produced by creating a rigid tympanic membrane with the existence of a pressure differential.

Resolution of the aerotitis media was documented by the return to baseline values following the Valsalva maneuver. Tympanometry readily distinguished, on the basis of ear canal volume, between negative pressure of an ear block and a greatly over-inflated middle ear produced by a Valsalva maneuver. It remains problematic

whether it could distinguish a partial overpressure from a "partial ear block." This is of practical importance since, in our opinion, some of the residual discomfort in patients following attempts to relieve aerotitis media may be from residual overpressure rather than from negative pressure in the middle ear.

The practical significance of our findings is that tympanometry offers an objective means of detecting aerotitis media and its resolution, making it a useful adjunct to management of that condition in the operational aeromedical environment. To date, detection in the operational environment has relied heavily on otoscopy which requires a skilled examiner. Results of otoscopy are subjective, and experienced examiners may be uncertain or disagree with the findings. Use of the tympanometer, on the other hand, requires less skill and gives little margin for subjective errors. The only caveat to the usefulness of the tympanometer was that it required modification to perform adequately at altitude.

Serial measurements of ear canal volumes made during ascent were performed to discern if data collected from the tympanometer could provide a reproducible marker of the existing altitude. The results of the present study suggest that they could.

Since the tympanometer interprets the less-dense pressure as an increased ear canal volume, it was thought that the pressure/volume change would correlate closely with Boyle's Law. Yet, as clearly shown in Fig. 3, the intercepts are similar but the slopes are very different. This discrepancy is thought to be related to the two reservoirs of air within the instrument, where a lower pressure in the fixed cell cavities lead to larger-than-actual ear canal volume calculations. Nevertheless, the tympanometer data appear to be reproducible. There were no significant differences observed between data collected at 586 mm Hg on ascent and values collected during a repeat exposure at the same pressure

TABLE II. COMPARISON OF TYMPANOMETER MEASUREMENTS BETWEEN PRE- AND POST-AEROTITIS MEDIA AND HYPOBARIC EXPOSURE.

	Aerotitis Media		Hypobaric Exposure	
	Pre	Post	Pre	Post
Ear Canal Volume	2.33 ± 0.09	2.32 ± 0.09	1.43 ± 0.08	1.43 ± 0.05
Tymp. Volume	0.96 ± 0.08	0.98 ± 0.06	0.75 ± 0.06	0.82 ± 0.05
Tymp. Pressure	-8.2 ± 2.5	-14.3 ± 4.5	-22.3 ± 2.4	-23.9 ± 3.9

Values are Mean ± S.E.M., ml, N = 62.

Tympanic membrane displacement volume (tymp volume).

Tympanic pressure in decaPascals (daPa).

There were no significant differences between pre and post measurements in all comparisons.

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following a brief sojourn to 522 mm Hg. There were also no differences in the tympanometry values between pre- and post-hypobaria (Table II). Because of these findings, it is believed that the tympanometer may prove to be helpful in managing aerotitis media insofar as the data collected could be used to determine the pressure/altitude of onset and resolution of the ear block. Additional investigations are necessary to determine if tympanometry data remain consistent at higher altitudes or with other tympanometer models.

The tympanometer may also be useful in other roles in the aeromedical environment—pre-flight screening for transient pathologic conditions of the middle ear such as upper respiratory infections and allergies, which have been implicated as a major cause of aerotitis media (7,20). Tympanometry may also be useful for disclosing post-flight residual pathological conditions. These should prove to be productive areas of future investigation.

### ADDENDUM

During tympanometer measurements, a low pitch tone (226 Hz) is presented to the tympanic membrane via a hand-held probe positioned against the entrance of the external ear canal. The probe tone is used to measure compliance changes within the middle ear system while air pressure within the ear canal is varied from a +200 decaPascals (daPa, 1.0 daPa = 0.039 in. H<sub>2</sub>O) to -400 daPa. In the absence of middle ear pathology, the middle ear system stiffens and becomes less mobile with either a greater positive or negative pressure, while the most compliance occurs when the pressure within the ear canal is brought back toward atmospheric pressure (i.e., 0 daPa). Therefore, by varying the pressure within the ear canal, it is possible to make a series of compliance measurements for evaluating tympanic membrane and middle ear status and Eustachian tube performance. The tympanic membrane compliance was plotted against the changes in pressure, creating a tympanogram. A final acoustic reflex test uses a loud sound (85–105 dB) at the same air pressure value of the compliance peak. The acoustic reflex stimulus serves to validate tympanometric results since an acoustic reflex cannot be measured in the absence of a compliance peak.

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Subjects participated in this study after giving their free informed, and voluntary consent. Investigators adhered to AR 70-25 and USAMRDC regulation 70-25 in use of volunteers in research. The views, opinions, and findings in this report are those of the authors alone.

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